Experimental Analysis Of Heat Transfer Rate In Plate Heat Exchanger By Corrugated Plate Structure With And Without Copper Coating

K.Raeventh kumar, S.Sathish kumar, M.Vijayaraj, S.Yuvaraj, A.Mahabubadsha

Abstract— **Experiments to measure and compare the convection heat transfer coefficient in gasket plate heat exchangers were performed with stainless steel plates and copper coated stainless steel plates. Gasket plate heat exchangers with corrugated structure was used to increase the heat transfer rate by increased exposure area and reduce fouling by creating turbulence flow between the plates. Here the thermal conductivity of copper is considered as a main concept to increase the heat transfer rate. By combining the effect of copper and corrugated structure, efficient heat transfer rate can be achieved in copper coated stainless steel plate when compared to stainless steel plate alone.**

Index Terms— **gasketed PHE; copper coating; heat transfer coefficient comparison**

I. INTRODUCTION

A. Introduction to Heat Exchangers:

A heat exchanger is a device used to transfer heat between a solid object and a fluid, or between two or more fluids. The fluids may be separated by a solid wall to prevent mixing or they may be in direct contact[1]. They are widely used in space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, natural-gas processing, and sewage treatment. The classic example of a heat exchanger is found in an internal combustion engine in which a circulating fluid known as engine coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air. Another example is the heat sink, which is a passive heat exchanger that transfers the heat generated by an electronic or a mechanical device to a fluid medium, often air or a liquid coolant.

A. Flow arrangement

There are three primary classifications of heat exchangers according to their flow arrangement. In parallel-flow heat exchangers, the two fluids enter the exchanger at the same end, and travel in parallel to one another to the other side. In counter-flow heat exchangers the fluids enter the exchanger from opposite ends. The counter current design is the most efficient, in that it can transfer the most heat from the heat (transfer) medium per unit mass due to the fact that the average temperature difference along any unit length is higher. See countercurrent exchange. In a cross-flow heat exchanger, the fluids travel roughly perpendicular to one another through the exchanger.

For efficiency, heat exchangers are designed to maximize the surface area of the wall between the two fluids, while minimizing resistance to fluid flow through the exchanger. The exchanger's performance can also be affected by the addition of fins or corrugations in one or both directions, which increase surface area and may channel fluid flow or induce turbulence.

In many heat exchangers, the fluids are separated by a heat transfer surface, and ideally they do not mix or leak. Such exchangers are referred to as direct transfer type, or simply recuperators. In contrast, exchangers in which there is intermittent heat exchange between the hot and cold fluids via thermal energy storage and release through the exchanger surface or matrix are referred to as indirect transfer type, or simply regenerators. Such exchangers usually have fluid leakage from one fluid stream to the other, due to pressure differences and matrix rotation/valve switching. Common examples of heat exchangers are shell-and tube exchangers, automobile radiators, condensers, evaporators, air preheaters, and cooling towers.

II. PLATE HEAT EXCHANGER

A. Introduction of PHE

A plate heat exchanger is a type of heat exchanger that uses metal plates to transfer heat between two fluids. This has a major advantage over a conventional heat exchanger in that the fluids are exposed to a much larger surface area because the fluids spread out over the plates. This facilitates the transfer of heat, and greatly increases the speed of the temperature change. Plate heat exchangers are now common and very small brazed versions are used in the hot-water sections of millions of combination boilers. The high heat transfer efficiency for such a small physical size has increased the domestic hot water (DHW) flowrate of combination boilers. The small plate heat exchanger has made a great impact in domestic heating and hot-water. Larger commercial versions use gaskets between the plates, whereas smaller versions tend to be brazed.

The concept behind a heat exchanger is the use of pipes or other containment vessels to heat or cool one fluid by transferring heat between it and another fluid. In most cases, the exchanger consists of a coiled pipe containing one fluid that passes through a chamber containing another fluid. The walls of the pipe are usually made of metal, or another substance with a high thermal conductivity, to facilitate the interchange, whereas the outer casing of the larger chamber is

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made of a plastic or coated with thermal insulation, to discourage heat from escaping from the exchanger.

The plate heat exchanger (PHE) was invented by Dr Richard Seligman in 1923 and revolutionised methods of indirect heating and cooling of fluids[2]. Dr Richard Seligman founded APV in 1910 as the Aluminium Plant & Vessel Company Limited, a specialist fabricating firm supplying welded vessels to the brewery and vegetable oil trades.

The corrugated pattern on the thermal plate induces a highly turbulent fluid flow. The high turbulence in the PHE leads to an enhanced heat transfer, to a low fouling rate, and to a reduced heat transfer area. Therefore, PHEs can be used as alternatives to shell-and-tube heat exchangers. R410A approximates an azeotropic behavior since it can be regarded as a pure substance because of the negligible temperature gliding.

The heat transfer and the pressure drop characteristics in PHEs are related to the hydraulic diameter, the increased heat transfer area, the number of the flow channels, and the profile of the corrugation waviness, such as the inclination angle, the corrugation amplitude, and the corrugation wavelength.

These geometric factors influence the separation, the boundary layer, and the vortex or swirl flow generation. However, earlier experimental and numerical works were restricted to a single-phase flow. Since the advent of a Brazed PHE (BPHE) in the 1990s, studies of the condensation and/or evaporation heat transfer have focused on their applications in refrigerating and air conditioning systems, but only a few studies have been done. Much work is needed to understand the features of the two-phase flow in the BPHEs with alternative refrigerants. Xiao yang experimented with the two-phase flow distribution in stacked PHEs at both vertical upward and downward flow orientations.

They indicated that non-uniform distributions were found and that the flow distribution was strongly affected by the total inlet flow rate, the vapor quality, the flow channel orientation, and the geometry of the inlet port Holger.

The geometric effects of the plate on the heat transfer and the pressure drop were investigated by varying the mass flux, the quality, and the condensation temperature.

B. *Types Of Plate Heat Exchangers*

Plate-type heat exchangers are usually built of thin plates (all prime surfaces). The plates are either smooth or have some form of corrugation, and they are either flat or wound in an exchanger. Plate heat exchangers can be classified as gasketed, welded (one or both fluid passages), or brazed, depending on the leak tightness required. Other plate-type exchangers are spiral plate, lamella, and plate coil exchangers.

C. *Advantages And Limitations*:

Some advantages of plate heat exchangers are as follows.

They can easily be taken apart into their individual components for cleaning, inspection, and maintenance.

The heat transfer surface area can readily be changed or rearranged for a different task or for anticipated changing loads, through the flexibility of plate size, corrugation patterns, and pass arrangements.

High shear rates and shear stresses, secondary flow, high turbulence, and mixing due to plate corrugation patterns reduce fouling to about 10 to 25% of that of a shell-and-tube exchanger, and enhance heat transfer.

Very high heat transfer coefficients are achieved due to the breakup and reattachment of boundary layers, swirl or vortex flow generation, and small hydraulic diameter flow passages.

Because of high heat transfer coefficients, reduced fouling, the absence of bypass and leakage streams, and pure counter flow arrangements, the surface area required for a plate exchanger is one-half to one-third that of a shell-and tube exchanger for a given heat duty, thus reducing the cost, overall volume, and space requirement for the exchanger.

III. EXPERIMENTAL SETUP

A. *Plate Heat Exchangers:*

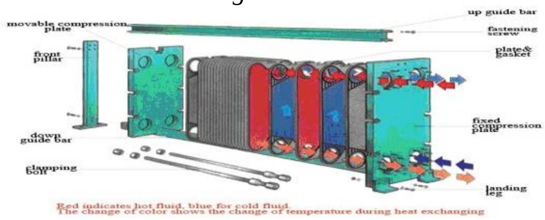

Fig. 3.1 Plate Heat Exchanger

The plate heat exchanger is formed up by a set of corrugated metal plates. The corrugated plates are mounted in a frame with a fixed plate on one side and a movable pressure plate and pressed together with tightening bolts. The corrugated plates serve not only to raise the level of turbulence, but also provide numerous supporting points to withstand the pressure difference between the media.

The hot medium may not flow through the apparatus without the cold medium flowing through. This is to prevent damage to the apparatus. In case the cold medium is present but does not flow while the hot medium is flowing through, the cold medium will start boiling and the apparatus will be damaged.

Sudden pressure and temperature changes should be prevented. When a heat exchanger (filled with water or a water mixture) which is not in operation is exposed to temperatures below zero, the plates can become deformed. If a danger of frost occurs, the heat exchanger should be drained completely.

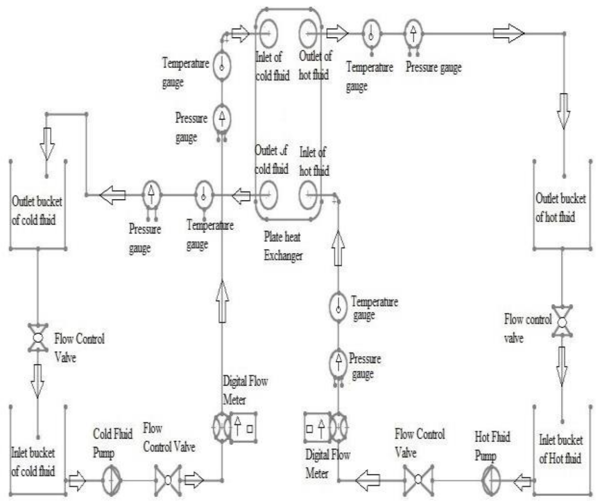

Fig. 3.2 schematic diagram of PHE

1) Parts Of Plate Heat Exchangers:

- Frames
- Plates
- Gaskets
- Flow Arrangements

B. General setup:

1. The zero correction of the thermocouples are determined by measuring steady the fluid inlet and outlet temperature under the following conditions (without switching on the heater).

 Stationary (Assuming the equipment is at equilibrium, before the start of the experiment, all the thermocouples should indicate the same temperature. Any deviation indicates the error of the thermometer/sensor combination)

 Allow minimal flow of the hot fluid and measure any temperature difference.

 Set the pump to maximum capacity flow rate (≈ 155 kg/h), and measure the temperature difference between the outlet and inlet of the hot fluid.

2. Set the temperature of the inlet hot fluid in the dual temperature indicator cum controller. The set point should be set around 65 to 70˚C.

3. Provide cooling water supply to the plate heat exchanger so that the flowrate is 111kg/h. This will ensure that the temperature rise is restricted to about 2–3˚C. Keep this flow rate constant throughout the experiment.

4. Connect the 15 A and 5 A plug pins to a stable 230 V A.C. electric supply. Care should be taken to connect these two pins in different phases of the power supply. Switch on the heater power supply.

5. Adjust the flow rate of hot fluid through the heat exchanger by adjusting the speed of hot fluid circulation pump. Note down the flow rate of hot fluid as indicated by the rotameter. If during the course of any experiment, the flow rate changes (due to power fluctuations, or due to temperature changes), to manually reset the flow rate to the desired set value. This kind of adjustments should be done for all the experiments to follow to ensure that the flow rate is maintained at a constant value.

C. *Flow distribution and heat transfer equation*

Design calculations of a plate heat exchanger include flow distribution and pressure drop and heat transfer. The former is an issue of Flow distribution in manifolds.[4] A layout configuration of plate heat exchanger can be usually simplified into a manifold system with two manifold headers for dividing and combining fluids, which can be categorized into U-type and Z-type arrangement according to flow direction in the headers, as shown in manifold arrangement. Bassiouny and Martin developed the previous theory of design[5][6]. In recent years Wang [7][8] unified all the main existing models and developed a most completed theory and design tool.

The total rate of heat transfer between the hot and cold fluids passing through a plate heat exchanger may be expressed as: Q = UAΔTm where U is the Overall heat transfer coefficient, A is the total plate area, and ΔTm is the Log mean temperature difference. U is dependent upon the heat transfer coefficients in the hot and cold streams [3].

IV. COPPER COATING THE HEAT TRANSFER PLATES

In order to increase the performance of plate heat exchanger we use the property of copper to transfer high rate of heat. Copper has high thermal conductivity, so it will increase the heat transfer rate.

1. Copper Coating By Electroplatting

There are several methods to coat a metal on a metal surface. Here electroplating method is used to coat the copper on the heat transfer plates.

1) Electroplating The Copper On Plate Surface

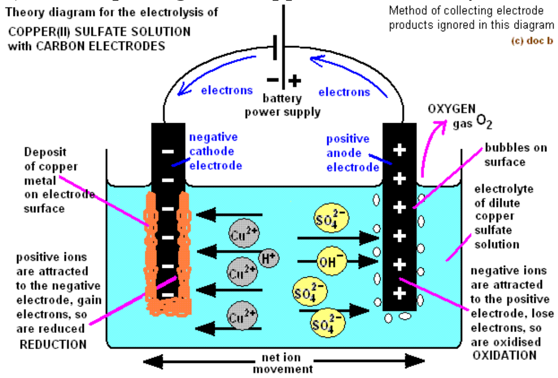

Fig. 4.1 Electroplating Setup

- Copper rod is taken as anode and plate is taken as cathode. Copper sulphate solution is used as electrolyte because copper is being to be plated.
- The following reactions are happened while the electrodes are powered by a DC battery.
- At cathode : Cu^{2+}(aq) + $2e^-$ → Cu
- At anode: Cu → Cu^{2+} (aq) + $2e^-$
- The valence copper atoms are being attracted by the plate in the cathode because of its positive charge nature.
- By this way the copper in the anode is coated in the heat transfer plates.
- The amount of copper deposited in the plate can be governed by Faraday's law.

V. CALCULATION

A. *Formula Used***:**

- Nusselt Number

$$Nu= 0.023Re^{0.8}\ Pr^{0.4}$$

- Over all heat transfer co-efficient

$$U= [1/h_i+1/h_o]^{-1}$$

- Heat Transfer Rate

$$Q = UA\ \Delta T_m$$

- Amount of copper deposited

V = K I t

Where, V-is the volume of metal plated in m3,
I-is the flowing current in ampere,
t-is the time for which current passes through, and
K-is a constant depending on electrochemical equivalent and density of electrolyte is m2/A – S.

B. *Used Values*

Hot fluid – hot water at 80^0C.

Cold fluid – normal water at 25^0C .

Mass flow rate – 0.25 lit/sec.
Heat transfer area – 0.2 sq.m
Properties of water are taken at respective temperature.
No.of plates – 7.
1-1 pass flow.

C. *Before Copper Coating On Ss 316 Plates*

FOR HOT FLUID:
Properties of hot fluid at 80^0C :
ρ = 971.6 kg/m^3
ν = 0.411×E^{-6} m^2/sec
C_p = 4196.07 j/kg.k
K = 0.670 w/m.k
μ = 0.000355 kg/ms

1. *Heat rejected by hot water:*
$Q = mC_{ph}\Delta T_h$
= 0.25*4193.07*(80-71)
= 9441.16 W
2. *Hot water mean temperature:*
$T_{avg} = (T_{hi}+T_{ho})/2$
$= \frac{80+71}{2}$
$T_{avg} = 75.5^0$c
3. *Hydraulic diameter:*
D_e = 2b
=2*0.007
= 0.014 m
4. *Flow area of hot water:*
$A_h = N_h$Wb
= 3*0.13*0.007
= 0.00273 m^2
5. *Velocity of hot water:*
$V_h = \frac{m_h}{A_h*\rho_h}$
$= \frac{0.25}{0.00273*971.6}$
= 0.09425 m/s
6. *Reynolds number for hot fluid:*
$Re_h = \frac{\rho_h V_h D_e}{\mu_h}$
$= \frac{971.6*0.09425*0.014}{0.000355}$
= 3611.34
7. *Prandlt number for hot fluid :*
$Pr_h = \frac{\mu_h C_{ph}}{k_h}$
$= \frac{4196.07*0.000355}{0.670}$
=2.223
8. *Nusselt number for hot fluid:*
Here Re > 2300 so taking relation for turbulent flow
$Nu_h = 0.662\ Re^{0.5} Pr^{0.33}$
9. *Heat transfer coefficient for hot fluid:*
$h_h = (0.662)\ (\frac{k_h}{D_e})\ Re^{0.5} Pr^{0.33}$ ($\because$ Nu = h. D_e/k)
= 0.662*(0.670/0.014)* $3611.34^{0.5} 2.223^{0.33}$
= 2478.16 W/ m^2k

FOR COLD FLUID:
Properties of cold fluid at 25^0C:
ρ= 997.13 kg/m^3
ν = 7.23×E^{-6} m^2/sec
C_p = 4180 j/kg.k
K = 0.6069 w/m.k
μ = 0.000891 kg/ms

10. *Heat gained by cold water:*
$Q = mC_{pc}\Delta T_c$
=0.25*4180*(33-25)
= 8360 W
11. *cold water mean temperature:*
$T_{avg} = (Tc_i+Tc_o)/2$
$= \frac{25+33}{2}$
$T_{avg} = 29^0$c
12. *Hydraulic diameter:*
D_e = 2b
=2*0.007
= 0.014 m
13. *Flow area of cold water:*
$A_c = N_c$Wb
= 3*0.13*0.007
= 0.00273 m^2
14. *Velocity of cold water:*
$V_c = \frac{m_c}{A_c*\rho_c}$
$= \frac{0.25}{0.00273*997.13}$
= 0.092 m/s
15. *Reynolds number for cold fluid:*
$Re_c = \frac{\rho_c V_c D_e}{\mu_c}$
$= \frac{997.13*0.092*0.014}{0.000891}$
= 1441.4
16. *Pradlt number for cold fluid :*
$Pr_c = \frac{\mu_c C_{pc}}{k_c}$
$= \frac{0.000891*4180}{0.6069}$
= 6.136
17. *Nusselt number for cold fluid:*
$Nu_c = 0.662\ Re^{0.5} Pr^{0.33}$
18. *Heat transfer coefficient for cold fluid:*
$h_c = (0.662)\ (\frac{k_c}{D_e})\ Re^{0.5} Pr^{0.33}$ ($\because$ Nu = h.d$_i$/k)
= 0.662*(0.6069/0.014)* $1441.4^{0.5} * 6.136^{0.33}$
= 1982.63 W/ m^2k
19. *Overall heat transfer coefficient:*
$\frac{1}{U} = \frac{1}{h_c} + \frac{1}{h_h} + \frac{t}{k_p}$
$= \frac{1}{1982.63} + \frac{1}{2478.16} + \frac{0.00006}{16.5}$
$\frac{1}{U} = 9.1155*10^{-4}$
U = 1097.03 W/ $m^2 k$
20. *LMTD:*
$\Delta T_m = \frac{(T_{hi}-T_{co}) - (T_{ho}-T_{ci})}{\ln[(T_{hi}-T_{co})/(T_{ho}-T_{ci})]}$
$= \frac{(80-33)-(71-25)}{\ln[(80-33)/(71-25)]}$
$= 46.49^0$ C

21. *Heat transfered:*

$Q = UA\ \Delta T_m$

$=1097.03*0.2*46.49$

$= 10200.185$ W

In the same way the heat transfer is calculated after copper coating the heat transfer plate.

VI. RESULT AND DISCUSSION

Chart 1 shows variation of convective heat transfer coefficient with respect to mass flow rate of cold fluid. Increase in mass flow rate results into increase in flow velocity of fluid, it leads to increase in Reynolds number which considerably increases heat transfer rate.

Chart-2 shows variation of convective heat transfer coefficient with Reynolds number. It is observed that heat transfer coefficient increases with increase in Reynolds number. Increase in Reynolds number is an indication that flow is becoming more turbulent and results into higher heat transfer rate.

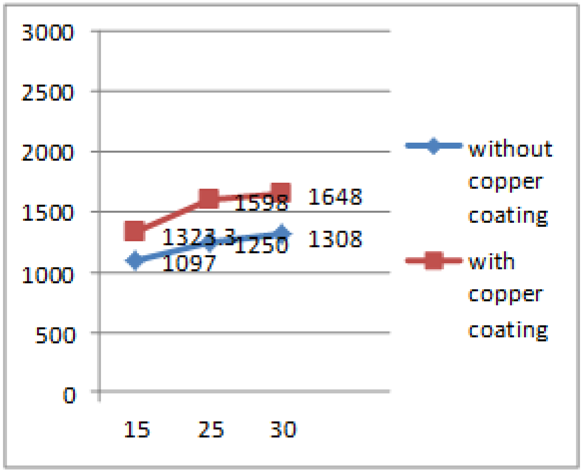

Chart 1- mass flow rate vs overall heat transfer coefficient

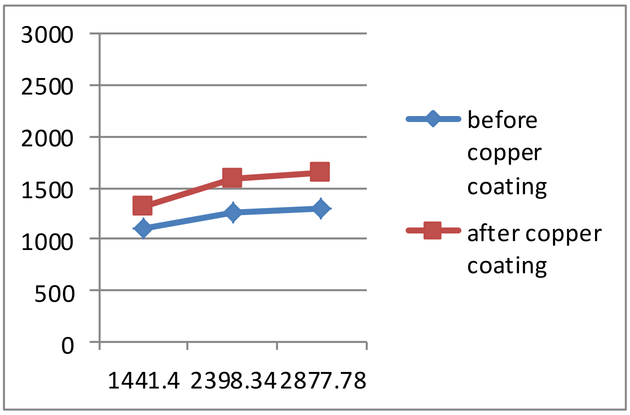

Chart 2- Reynolds number vs overall heat transfer coefficient

VII. CONCLUSION:

By using the above work we can conclude that copper coated plates have more heat transfer rate than heat transfer plate without copper coating. While using copper coating overall heat transfer rate is increased up to 15%. Also plate heat exchanger having 3 or more times more heat transfer co-efficient than shell and tube heat exchanger. This approach is suitable and simple tool for use in the determination of overall heat transfer co-efficient and heat transfer rate.

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